Imaging H I Absorption toward Symmetric Radio Galaxies – Evidence for a Circumnuclear Torus

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Abstract

Recent VLBI observations have identified several compact radio sources which have symmetric structures on parsec scales, and exhibit H I absorption which appears to be associated with the active nucleus. These sources are uniquely well suited to investigations into the physics of the central engines, in particular to studies of the kinematics of the gas within 100 pc of the core. In these compact sources, it is reasonable to assume that this circumnuclear material is accreting onto, and "feeding", the central engine.

We present results of H I imaging studies of 3 symmetric radio galaxies which show evidence of a circumnuclear torus.

1 Introduction

A number of active galactic nuclei (AGN) have been found to exhibit HI absorption toward the central parsecs. Models which have been proposed to explain this absorption suggest that disk or torus structures exist in AGN on scales ≤100 pc from the central engine (Conway 1996). The orientation of the radio axis of the source with respect to our line of sight determines whether or not this structure is detectable in absorption. Core-dominated radio sources are oriented close to the line of sight and have relativistic jets. This causes the approaching jet to be strongly Doppler boosted, while the counterjet is Doppler dimmed. Symmetric sources, on the other hand, are oriented at larger angles to the line of sight and may have hot spots that advance at subrelativistic velocities (Owsianik & Conway 1998). The continuum emission is not

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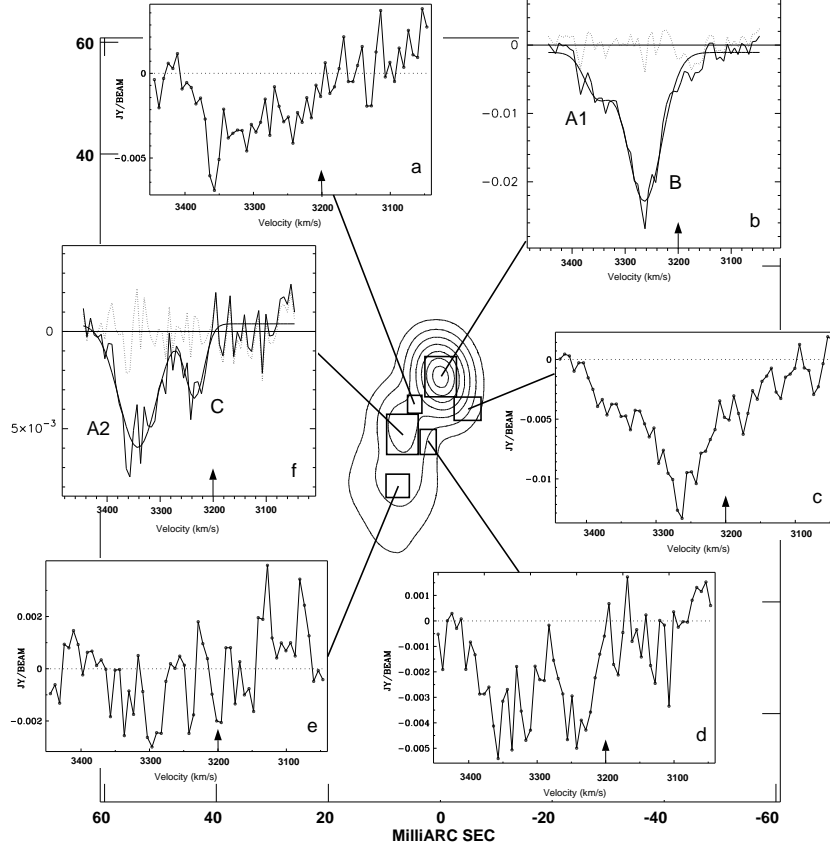[2] E-mail: apeck@nrao.edu, gtaylor@nrao.edu

Fig. 1. H I absorption profiles toward 1146+596 overlayed on 1.4 GHz continuum contours (Peck & Taylor 1998). The systemic velocity is indicated by an arrow in each panel.

strongly beamed, and thus the counterjet can contain about half of the flux density. If the source is oriented close enough to the plane of the sky, obscuration by a circumnuclear torus can then be detected against the jet, counterjet, and core. A significant fraction of neutral atomic gas can be expected within a range of radii determined by the midplane pressure in the circumnuclear structure (Neufeld & Maloney 1995). As predicted by this model, the majority of detections of 21 cm atomic hydrogen seen in absorption toward the cores of galaxies has been in Compact Symmetric Objects (CSOs) and in extended radio galaxies which are symmetric on VLBI scales, rather than in core-dominated radio sources (van Gorkom et al. 1989).

2   Results

1146+596

1146+596 is associated with the nearby (z=0.0107) elliptical galaxy, NGC 3894. Although too underluminous to be formally classified as a CSO, 1146+596
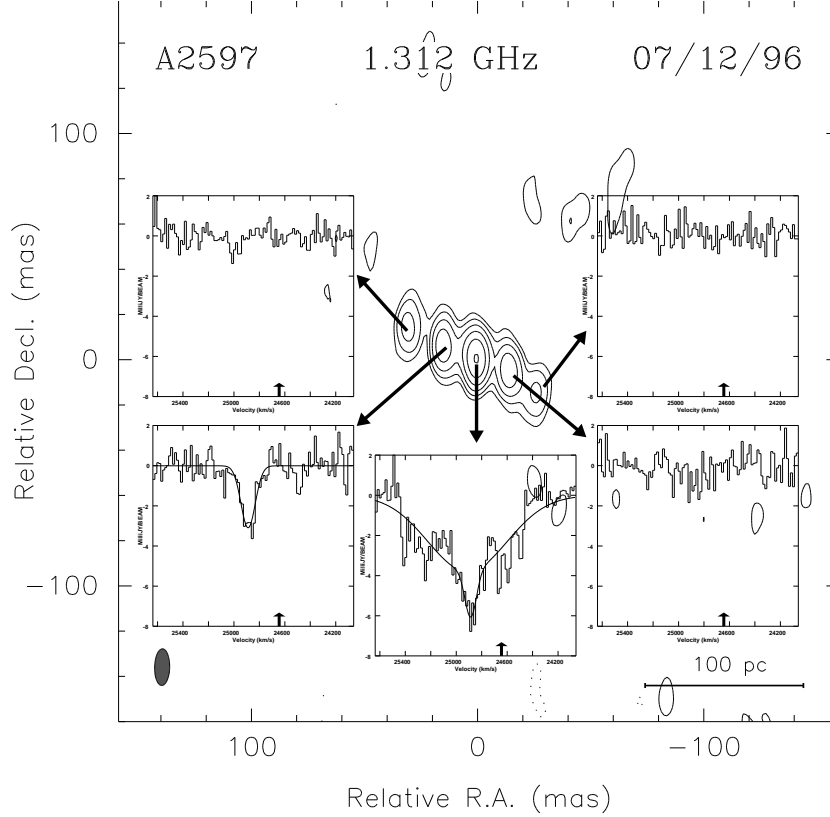
Fig. 2. H I absorption profiles toward PKS 2322-123 overlayed on 1.3 GHz continuum contours (Taylor et al. 1999). The systemic velocity is indicated by an arrow.

shares the principal characteristics which lead to the detection of H I absorption in this class of objects. Namely, it is compact, and oriented such that a circumnuclear disk or torus should be observable in absorption.

Strong absorption lines are detected toward both the approaching and receding jets. Absorption profiles integrated over 6 regions across the source are shown in Figure 1. At least two velocity components are present in all lines of sight except toward the SE lobe (panel 1e), where the signal to noise ratio is low due to the weak continuum emission in that region. The strongest absorption feature is seen toward the approaching jet, shown in panel 1b. The optical depth of this strong feature is $\tau = 0.12 \pm 0.01$. Although the absorption components are broader than those found toward the center of our own Galaxy, (e.g. Liszt et al. 1983), the blending of the lines and the low signal to noise make it impossible to detemine conclusively whether the absorption is associated with the AGN or due to intervening clouds in the host galaxy. Further observations of this source are needed.

PKS 2322−123

PKS 2322−123 is a cD galaxy at a redshift of $z=0.082$. VLBA observations of this source reveal straight and symmetric jets emerging from both sides

of an inverted spectrum core. H$\textsc{i}$ is detected in absorption against the core and eastern jet with substantial opacities, but is not seen towards the equally strong western jet. In the profiles shown in Figure 2, two distinct absorption components are present, although the very broad line (735 km s^{-1} FWHM) is seen only against the core. The optical depth of the narrow line is τ=0.63 and that of the broad line is τ=0.26. Both lines are redshifted ($\sim$220 $\pm$ 100 km s^{-1}) with respect to the systemic velocity. The fact that both lines in PKS 2322$-$123 are redshifted may imply that the gas is infalling. This is similar to the trend found by van Gorkom et al. (1989) for 6 of 8 H$\textsc{i}$ absorption systems in a sample of nearby ellipticals.

The most likely explanation for the observed H$\textsc{i}$ kinematics are an atomic torus centered on the nucleus with considerable turbulence and inward streaming motions. The scale height of this torus is less than 20 pc. Unfortunately, because the radio axis of this source is so close to the plane of the sky, we see the torus edge-on and thus have no information about its radius. Assuming a radius of 10 pc, the mass required to produce the observed linewidth of 735 km s^{-1} is 2 $\times10^8$ M$_\odot$.

1946+708

The radio source 1946+708 is a Compact Symmetric Object (CSO) associated with a m$_v$=18 galaxy at a redshift of z=0.101. Figure 3 shows the H$\textsc{i}$ absorption profile toward each of 5 regions across the source. Although there is clear evidence of absorption toward each region, it is unclear how many distinct components are present in each profile. With the exception of the profile toward the northern hot spot (NHS+N1), a single Gaussian function has been fitted to each profile. The systemic velocity obtained from optical observations of both emission and stellar absorption lines is 30279$\pm$300 km s^{-1} (Stickel & Kühr 1993). All of the H$\textsc{i}$ absorption features reported here are within one sigma of the systemic velocity.

Narrow lines seen toward the northern hotspot which marks the approaching jet are probably due to small clouds of H$\textsc{i}$ associated with an extended "clumpy" torus of warm gas. The high velocity dispersion and column density toward the core of the source, however, are indicative of fast moving circumnuclear gas, perhaps in a rotating toroidal structure. Further evidence for this region of high kinetic energy and column density is found in the spectra of the jet components, which indicate a region of free-free absorption along the line of sight toward the core and inner receding jet (Peck, Taylor & Conway 1999). The most likely scenario to explain these phenomena consists of an ionized region around the central engine, surrounded by an accretion disk or torus with a radius of at least 50 pc which is comprised primarily of atomic gas.
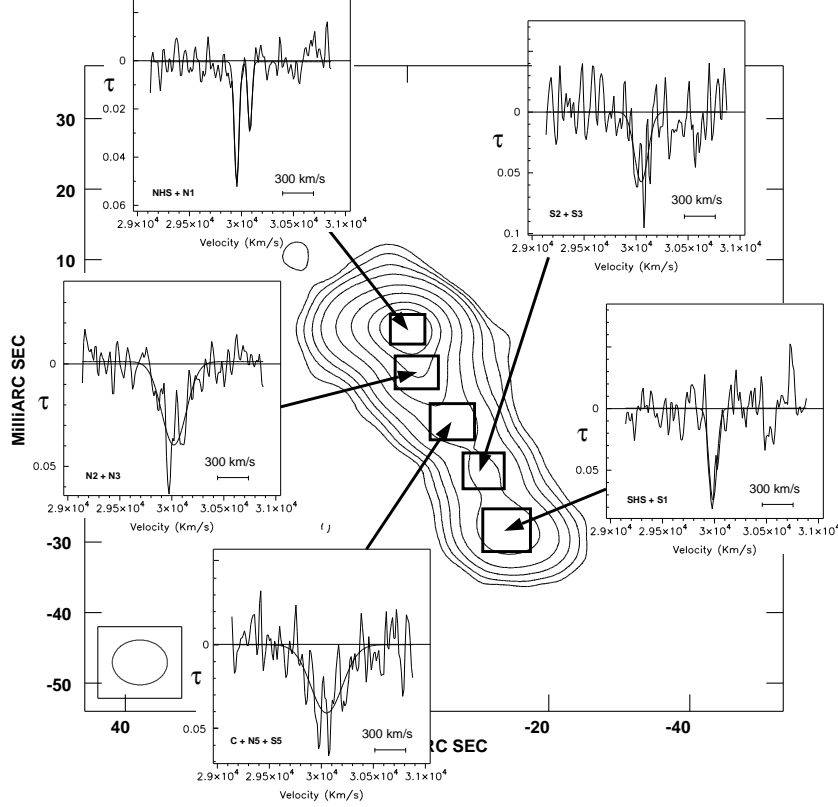
Fig. 3. H I absorption profiles toward the CSO 1946+708 overlayed on 1.3 GHz continuum contours (Peck, Taylor & Conway 1999).

3   Summary

Of the three symmetric radio sources presented here which exhibit H I absorption toward the core, we find that two of them are strongly indicative of a circumnuclear torus. The third requires further investigation. All three sources, however, yield strikingly different absorption profiles than those found in nearby asymmetric radio sources. In Centaurus A, for example, three very strong absorption features are found. The optical depths of the three lines vary little across the continuum source, and the FWHM linewidths are between 7–20 km s^{-1} (van der Hulst, Grolisch & Haschick 1983, Peck 1999). Comparison between these two types of absorption systems is discussed further in Peck (1999).

In the symmetric sources shown here, in which the lines are very broad and the highest column densities are centered on the cores, it is reasonable to assume that this circumnuclear material is accreting onto, and "feeding", the central engine, and that this process will lead to their eventual evolution into much larger FR II sources (Readhead et al. 1996, Fanti et al. 1995). This torus is also expected to obscure the central parsecs of sources which happen to be oriented at large angles to the line of sight, resulting in the observed differences

between the Type I (quasar, Seyfert 1) and Type II (radio galaxy, Seyfert 2) objects.

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